

## **Final Technical Report**

### **Active Fault Investigations on the Canyon River Fault, Southern Olympic Range, Washington**

by

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### **Abstract**

The Canyon River Fault (CRF) strikes N60°E. Its dip ranges from 60°S to vertical. Separation is south over north, placing basalts of the upper Crescent Formation against the lower Crescent. It is well exposed in the southeast Olympic Mountains, where for a distance of several miles it forms a north-facing scarp on both north- and south-facing slopes. It is part of a regional lineament that is readily visible on aerial photography and sidelooking airborne radar imagery for a distance of at least 30 miles.

The fault trace is most clearly exposed near the western boundary of Mason County in section 19

of T.22N., R.6W., W.M., where it is aligned subparallel to the valley floor of the Canyon River and a tributary. The fault trace has been incised by two local, unnamed perennial streams. In one of these streams, sediments that were impounded by the upthrown fault block are exposed in stream channel walls. Sheared basalt bedrock is exposed in the channel and its walls downstream from the fault. Where the other stream crosses the fault at a low angle, the fault scarp has diverted the stream along the fault trace and left a short segment of channel that was incised into basaltic bedrock stranded above the active channel. We obtained a radiocarbon age of  $1,880 \pm 70$  ybp (Beta 109347) on abundant detrital charcoal from a silt draped over remnant boulder gravel in the abandoned channel, suggesting fault movement more recently than about 2,000 radiocarbon years ago. A vegetated older terrace within the active channel of the stream grades to the draped silt and probably represents both debris flow and lacustrine sediments deposited in the lake impounded by the combination of fault scarp and logjam in the narrow channel. We have not yet found piercing points to convincingly demonstrate the direction of slip, but the geometry of the channel offset suggests to us pure high-angle reverse slip.

The surface expression of the fault is a linear break in the valley floor approximately 3 m high. The terrain both north and south of the fault is relatively level and forested and is locally covered by standing water in two of the sag ponds. We hope to trench the fault adjacent to one of these sag pond to obtain information on recurrence interval.

### **Introduction**

Recent work has established that a number of aligned earthquake epicenters are shallow enough to have produced surface rupture in western Washington. (See Rogers and others, 1996, for a summary.) However, only two mapped faults, the Saddle Mountain East and West faults (Fig.1), have been shown to have Holocene surface rupture (Wilson and others, 1979). We have identified another fault 24 km west-southwest of these that has a similar, that is, reverse sense of separation and apparent Holocene offset. We have named it the Canyon River fault (CRF). It is part of a discontinuous lineament that is at least 30 miles long that is approximately coincident with a side-looking airborne radar lineament that has been called the Spoon Creek lineament (U.S. Army Corps of Engineers, 1983). Our preliminary work suggests that the CRF has been active within the last 2,000 years. If the CRF is seismogenic, earthquakes along this fault could be on the order of M6.5-7 (Wells and Coppersmith, 1994), large enough to put several dams and small cities at risk.

There are many late Holocene seismically induced features, such as landslide-dammed lakes and uplifted and subsided land surfaces (Rogers and others, 1996; Gower and others, 1985; Atwater and Moore, 1992; Bucknam and others, 1992; Karlin and Abella, 1992; Jacoby and others, 1992; Logan and Walsh, 1995; Schuster and others, 1992; Logan and others, 1998; Washington Division of Geology and Earth Resources (DGER), unpublished data; U.S. Forest Service, unpublished data) that are spatially and temporally associated with these faults. This mostly indirect evidence supports the occurrence of several major late Holocene seismic events in the vicinity of the CRF.

The CRF is at the contact between the upper and lower members of the Crescent Formation, as mapped by Tabor and Cady (1978). Glassley (1974) recognized faulting along this contact in other parts of the Olympics and inferred it to be a fault contact everywhere on the basis of differences in metamorphic grade. Babcock and others (1992), however, found that the faulting is not a single continuous structure and that the tectonic disruption is undoubtedly far more complex than the simple thrust of upper member over lower member.

The CRF strikes N60°E (Figs. 1, 2, 3) and dips between 60°S and vertical (Fig. 4). It is well exposed in the southeast Olympic Mountains where, for a distance of several miles, it forms a north-facing scarp on both north- and south-facing slopes. It appears from regional geology and a few ambiguous horizontal slickensides that it may have a small component of right-lateral slip, but the consistency of its scarp and the lack of offset in channels incised into bedrock suggest that it is principally a reverse fault. It is part of a regional lineament that is readily visible on aerial photography (Fig. 3) and sidelooking airborne radar imagery for a distance of at least 30 miles.

McCrary (1997; 1996) has described faulting and folding in Quaternary sediments along the west side of the Olympic Peninsula. These structures reflect both east-west shortening related to northeastward convergence and north-south shortening related either to broad northwest-southeast shearing between the Pacific and North America plates or to the margin-parallel component of oblique convergence between the Juan de Fuca and North America plates. She proposed that sediments deposited at the base of the accretionary wedge respond to stresses associated with plate convergence, but that structures higher in the accretionary prism respond to modern north-south compression (Magee and Zoback, 1992; Ma and others, 1996).

We infer that the CRF may have accommodated early thrusting in the Crescent Formation related to Juan de Fuca plate subduction but is now reactivated as a high-angle reverse fault in response to modern shallow north-south compression.

### **Results**

The fault trace is most clearly exposed near the western boundary of Mason County in sec. 19 of T.22N., R.6W., W.M., where it is aligned subparallel to the valley floor of the Canyon River and a tributary (Figs. 2, 3). The fault trace has been incised by two unnamed perennial streams. In one of these streams (Fig 3, Location 1), sediments that we infer to have been impounded by the upthrown fault block are exposed in stream channel walls (Fig. 5). Wood that was buried by these sediments yielded a Radiocarbon-infinite age (Beta 118329). Sheared basalt bedrock is exposed in the channel and its walls downstream from the fault (Fig 4). Where the other stream crosses the fault at a low angle (Fig. 3, Location 2), the fault scarp has diverted the stream along the fault trace and left a short segment of channel that was incised into basaltic bedrock stranded above the active channel (Figs. 6, 7). Youthfulness of the fault is also suggested by the observation that the fault scarp has produced sag ponds but has not captured this stream, which remains in its engorged channel (Fig. 8).

We obtained a radiocarbon age of  $1,880 \pm 70$  yr B.P. (Beta 109347) on abundant detrital charcoal from a silt draped over remnant boulder gravel in the abandoned channel, suggesting fault movement more recent than about 2,000 radiocarbon years ago. We have not yet found piercing points to convincingly demonstrate the direction of slip. The geometry of the channel offset has no apparent lateral component, and the scarp is consistently north-facing, regardless of topography, suggesting to us a pure high-angle reverse slip in the last movement. We have found a few sets of horizontal slickensides, however, that suggest the fault may also have a component of right-lateral slip. We infer that the CRF dominantly accommodates north-south compression but perhaps also a component of Juan de Fuca plate convergence.

Surface expression of the fault is a linear break in the valley floor approximately 3 m high. The terrain both north and south of the fault is relatively level and forested and is locally covered by standing water in two sag ponds. At the location labeled "proposed trench site" on Fig. 3, we, S. P. Palmer and Walter Barnhardt performed a ground penetrating radar survey to determine the likely thickness of sediment filling the sag pond (see appendix by S. P. Palmer for details). The sag pond appears to have between 10 and 20 feet of sediment accumulation on top of bedrock to the south and laps onto a colluvial wedge shed from the fault scarp. We hope to trench the fault adjacent to and into this sag pond to obtain information on recurrence interval.

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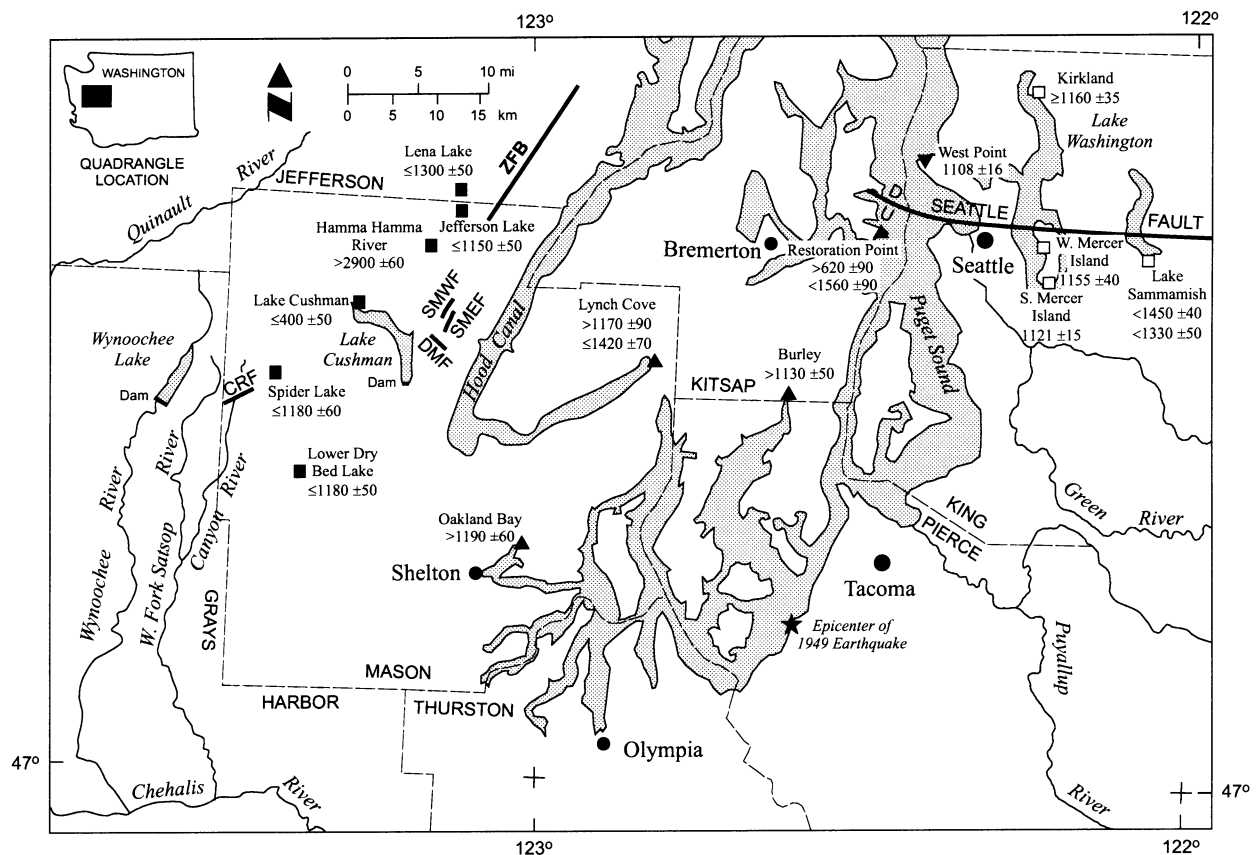
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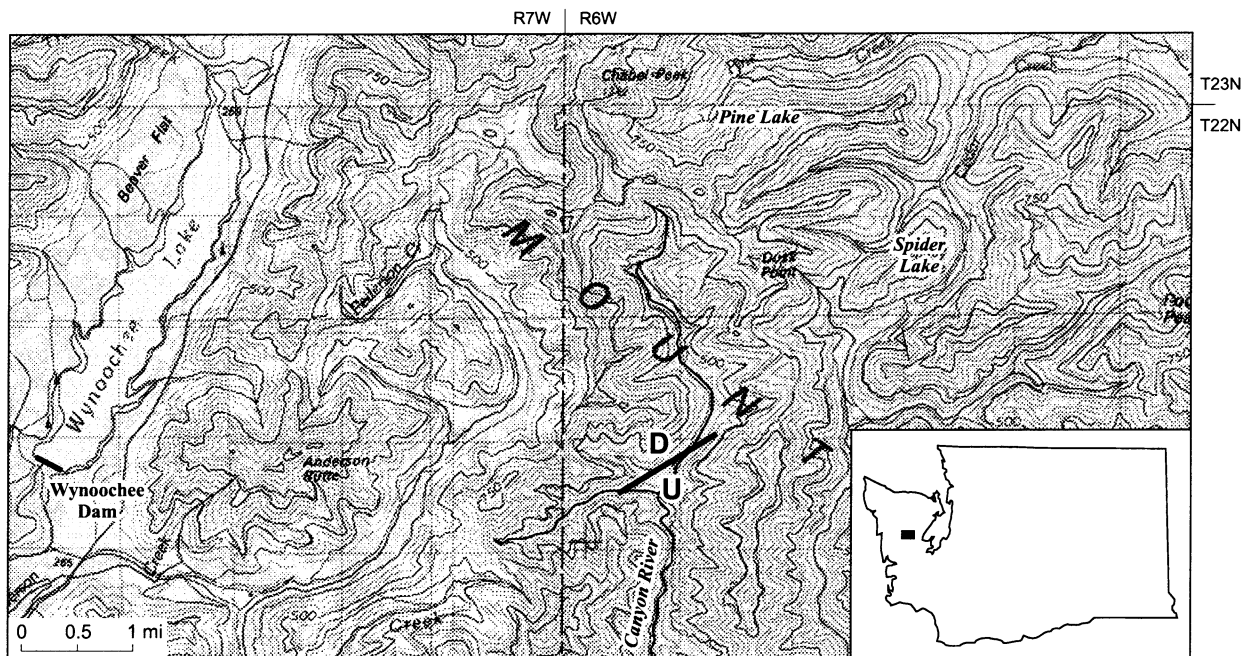
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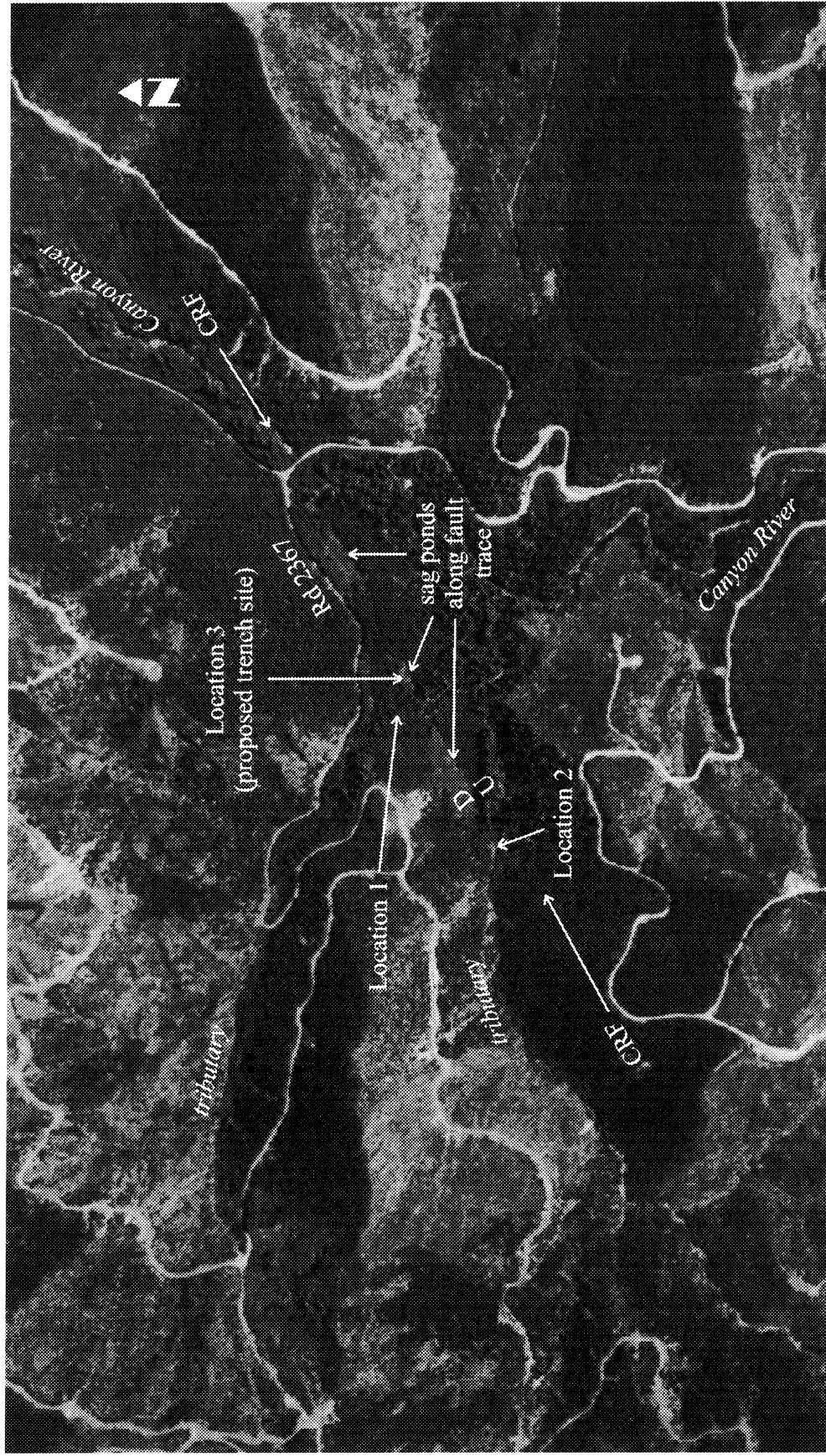
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**Figure 1.** General location of the Canyon River fault (CRF). The fault lies between Wynoochee and Cushman dams, which impound large reservoirs upstream of inhabited areas. Significant nearby features, shown with radiocarbon ages, include: seismically induced landslides ( $\square$ ), landslide-dammed lakes ( $\blacksquare$ ), and uplifted ( $\blacktriangle$ ) or subsided ( $\blacktriangledown$ ) estuaries. DMF, Dow Mountain fault; SMWF, Saddle Mountain West fault; SMEF, Saddle Mountain East fault; ZFB, zone of fractured basalt of Glassley, 1974.



**Figure 2.** Location and known extent of the N60°E-trending fault scarp. Note that Wynoochee dam, which impounds the water supply for the city of Aberdeen and is upstream of a number of homesites and State Route 12, is located less than 10 km from the scarp. Spider Lake, a suspected seismically induced landslide-dammed lake, is within 3 km. Contour interval is 50 m. Printed from TOPO! 1997 Wildflower Productions ([www.topo.com](http://www.topo.com)).



**Figure 3.** 1992 aerial photo of the Canyon River fault (CRF). The proposed trench site will cross the fault at the center sag pond, which is dry most of the year and is accessible by an overgrown skid road. Note that despite dense regrowth over a previous clearcut, the fault trace remains visible from the air, a rarity in western Washington. Scale is approximately 1:9,500.

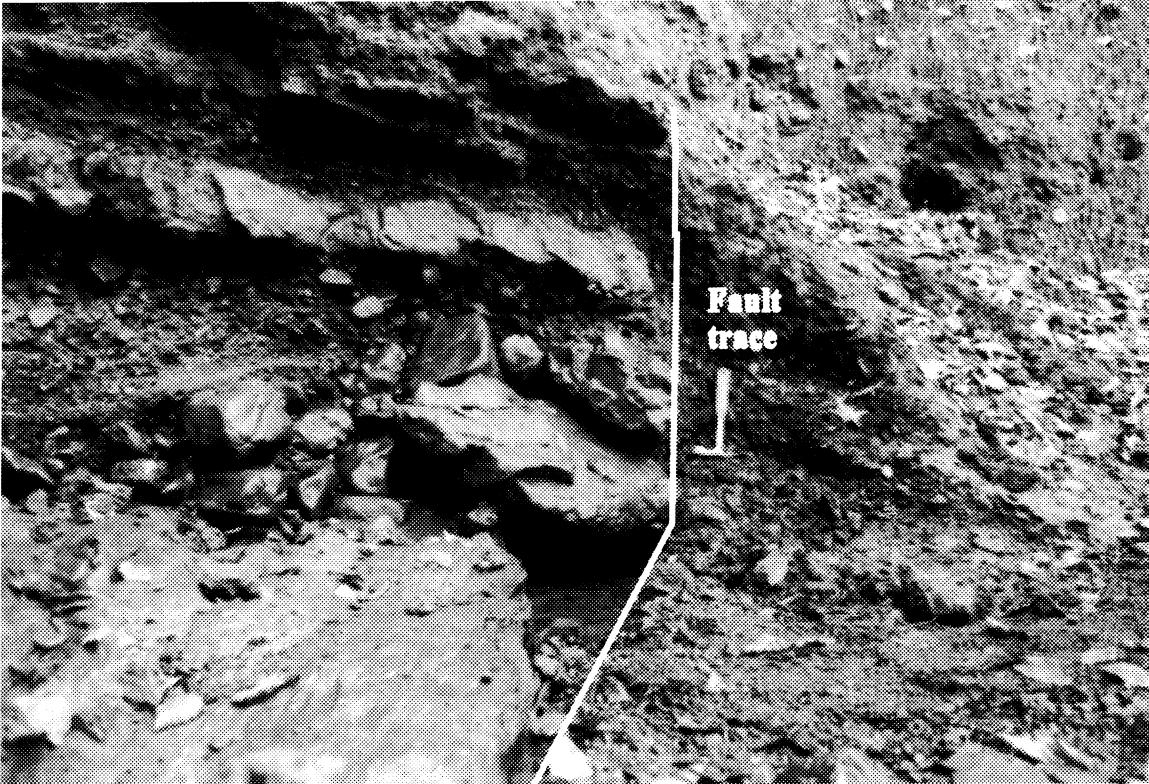




**Figure 4.** Exposure of the fault plane in the bedrock walls of a small tributary to the Canyon River (Location 2, Fig. 3). The fault plane strikes N60°E and dips about 70° to the south. Subhorizontal slickensides with a right-lateral sense of chatter were found here. View is to the northwest.



**Figure 5.** This photo (Location 1 on Figure 3), taken about 50 m upstream of the CRF, shows horizontal (behind the pick) sediments that were deposited after the the upthrown block dammed the stream. A layer of sediment consisting of poorly sorted angular clasts (probably a debris flow deposit that crops out elsewhere) has been eroded away here. The exposed silt unit weathers orange and is about 15 cm thick. It is underlain by another coarse debris flow deposit. The boulders here are derived from pillow basalts of the lower Crescent Formation (Tabor and Cady, 1978), which is exposed in the stream bed a short distance upstream. The thickness of the fault-dammed sediments is unknown due to poor exposure. Wood found in this material was radiocarbon-infinite.



**Figure 6.** Truncated colluvium exposed in the south bank of an unnamed tributary to the Canyon River (Location 2 on Figure 3). Note the apparent drag folds in clay layers to the right and left of the pick. The deformed clay layers contain abundant charcoal and are separated by coarser colluvium. The approximate fault trace is shown by the dashed line. At this locality, the fault trace is easily recognized in the stream bed because the upthrown block is scoured to sheared basaltic bedrock, but the younger alluvium has deposited in the present channel adjacent to the scarp. Shears within the basalt project from left to right directly toward the deformed clay beds.



**Figure 7.** The upthrown block, about 15 m downstream of Figure 6. Where the geologist is standing, the stream channel is scoured to bedrock and is covered with basalt boulders. To his left, silt is draped over the boulders and is overlain by a thick sequence of gravelly colluvium . We infer that the silt was deposited by flooding soon after this channel was uplifted. A radiocarbon age of  $1,880 \pm 70$  yr B.P. (Beta 109347) was obtained from abundant detrital charcoal in the silt.





**Figure 8.** Sag pond along the Canyon River Fault. This is the southwesternmost sag pond in Figure 3. Smaller trees grow to the edge of the scarp, whereas the downthrown side of the fault is marshy and devoid of trees. View is to the southeast from a road about 150 ft above the pond.



**Appendix**  
**Ground Penetrating Radar Investigation of the Canyon River Fault**

by

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**Introduction**

A ground penetrating radar (GPR) survey was performed in order to determine the depth to the Crescent Basalt bedrock presumably offset by the Canyon River Fault. This information will be necessary in future trenching of the fault at the survey location to determine size of excavator, length and depth of trench shoring, etc.

GPR data was acquired along two profiles aligned normal to the fault scarp at sites considered for future trenching investigations. A survey map of these two profiles is presented in Figure A-1. GPR data acquisition was performed by Dr. Walter Barnard of the U.S. Geological Survey, Western Region, Coastal and Marine Geology and myself using his Pulse Echo IV (registered trademark of Systems & Software, Inc.) ground penetrating radar system. I processed and displayed these GPR data using WinSeis (registered trademark of the Kansas Geological Survey), a seismic data processing and display software package.

GPR data was acquired along profiles TR-1 and TR-2 using 100 Mhz antennas with an 800 picosec sampling rate and a total record length of 600 nanosec. GPR source-receiver spacing was approximately 3 ft; trace spacing along TR-1 is 1.0 ft, and along TR-2 it was 0.5 ft. The ground surface was relatively level along the profiles except at the fault scarp crossing, but forest duff soils and woody debris degraded ground coupling of the source and receiver antennas. A tape and level survey of the profile lines (see Figure A-1) was performed in order to use an elevation datum in the display of the GPR data.

Data processing was comprised of conversion of the GPR data to KGS format, low-cut filtering to remove ground inductance coupling of the source and receiver antennas, and application of an automatic gain control (AGC) to balance the trace amplitude over the entire record length. The GPR profiles were referred to an elevation datum by applying a static shift based on an assumed wave propagation velocity of 0.05 m/nanosec, which is a typical value for saturated granular sediments. Consequently the depths displayed on the right side of profiles TR-2 and TR-1 (figures A-2 and A-3, respectively) are based on this assumed velocity.

## **Interpretation of GPR Profile TR-2**

GPR profile TR-2 (Figure A-2) runs across the western portion of the fault scarp where it is exposed on the southern edge of the low-lying valley (sag pond) considered as a candidate area for future trenching. This profile crosses the fault scarp and continues along the upthrown side of the fault (see Figure A-1).

The orange reflector shown in Figure A-2 is interpreted as originating from the sediment-bedrock interface. Between stations 1 and 46 the orange reflector is a coherent, high-amplitude event that is relatively flat-lying. The arcing reflectors below 225 nanosec between stations 51 and 96 are interpreted as diffractions originating along the fault plane. These diffractions mask the continuation of the bedrock reflector to the fault plane between stations 46 and 81. Mapping of the bedrock reflector to the fault plane is based on following a semi-coherent, high-amplitude event just below 400 nanosec between stations 51 to 66, and projecting that event to the fault. The coherent, high amplitude reflector just below 200 nanosec in the vicinity of station 101 is interpreted as the top surface of bedrock on the upthrown side of the fault.

A transparent interval (up to 4.0 m (13.5 ft) thick) lies above the orange (bedrock) reflector between stations 1 to 55. This section is interpreted as peat and lacustrine sediments that have accumulated in the sag pond in response to movement on the fault. Shallower reflectors dip into the sag pond between stations 51 to 81, and are interpreted as a debris fan resulting from erosion of the fault scarp.

Based on this interpretation and the assumed velocity used in the time-depth calculation, bedrock on the downthrown side of the fault is at a depth of 5 to 6 m (16.5 to 20 ft) below ground surface. On the upthrown side of the fault bedrock is at a depth of approximately 3 m (10 ft).

## **Interpretation of GPR Profile TR-1**

GPR profile TR-1 (Figure A-3) runs across the eastern portion of the fault scarp where it is exposed on the southern edge of the sag pond considered as a candidate area for future trenching. This profile only runs to the base of the fault scarp as attempts to acquire data traversing the scarp at this site proved impractical.

The orange reflector shown in Figure A-2 is interpreted as originating from the sediment-bedrock interface. Between stations 91 and 125 the orange reflector is a coherent, high-amplitude event that dips slightly away from the scarp. North of station 91 this reflector loses coherency, and cannot be mapped with confidence. Similar to profile TR-1, a transparent interval (up to 4.0 m (13.5 ft) thick) lies above the orange (bedrock) reflector, and is likewise interpreted as peat and lacustrine sediments that have accumulated in the sag pond. A shallow reflector mapped in yellow between stations 1 and 91 is interpreted as a fan resulting from debris flows originating on the steep slope bounding the north side of the sag pond.

Based on this interpretation and the assumed velocity used in the time-depth calculation, bedrock on the downthrown side of the fault is at a depth of 3 to 4 m (10 to 13.5 ft) below ground surface. Depth to bedrock on the upthrown side of the fault cannot be estimated.

### **Conclusions**

GPR profiles acquired across the scarp of the Canyon River Fault provide some estimate for the likely depth to bedrock to be used in planning future trenching investigations. Depth to bedrock along the downthrown side of the fault appears to vary between 3 to 6 m (10 to 20 ft) along the scarp. Depth to bedrock is approximately 3 m (10 ft) on the upthrown side of the fault along profile TR-2. No estimate for bedrock depth on the upthrown side of the fault is available along profile TR-1.



CANYON RIVER FAULT  
MAY 11, 1998 GPR SURVEY  
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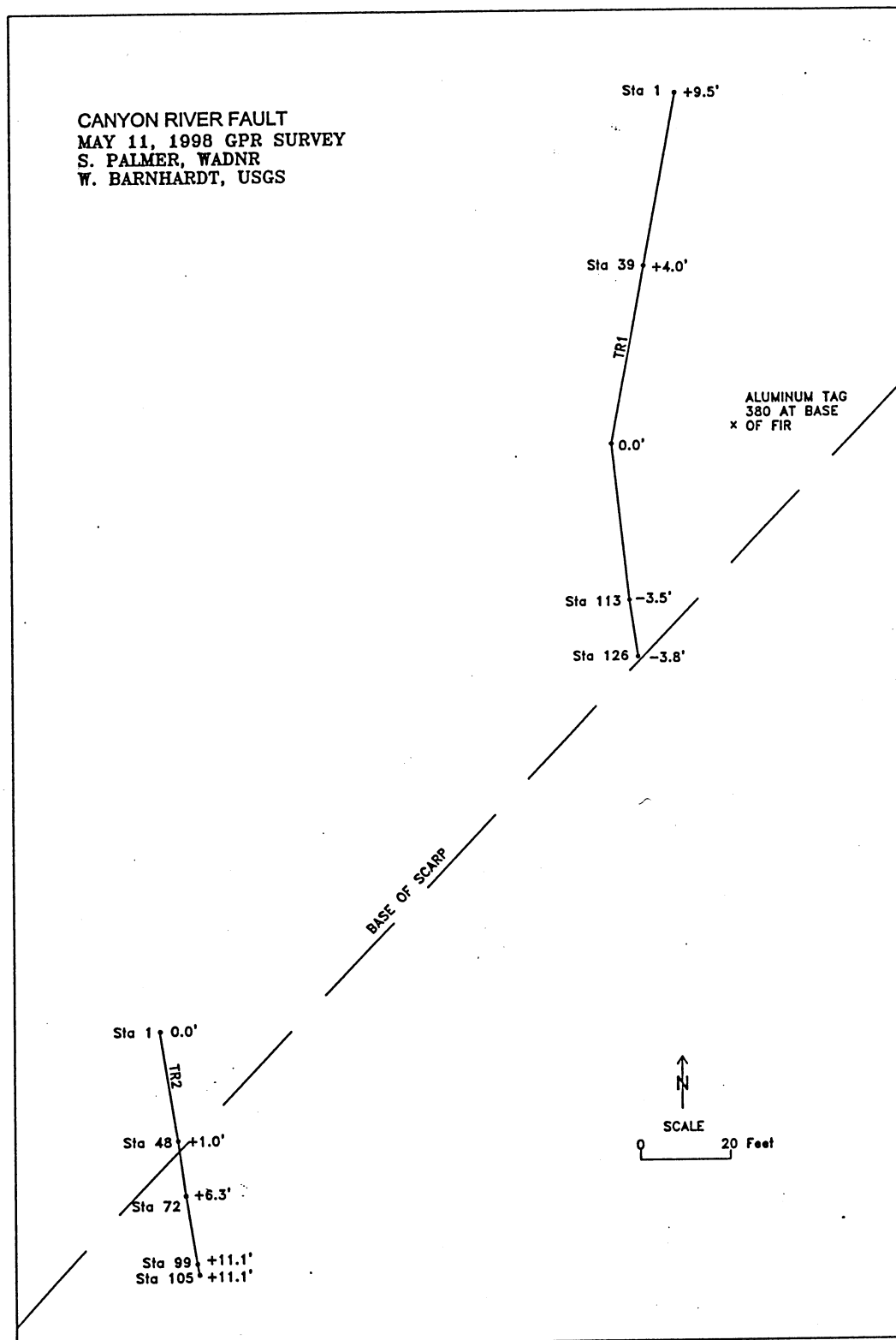
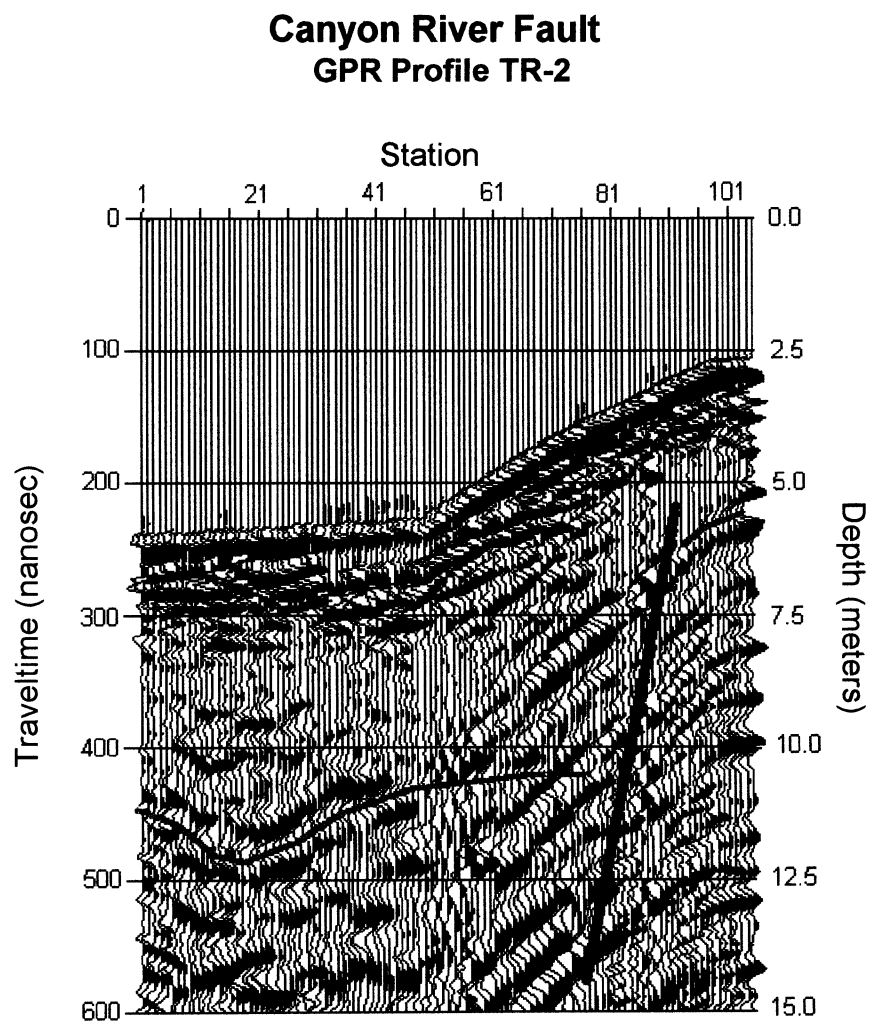


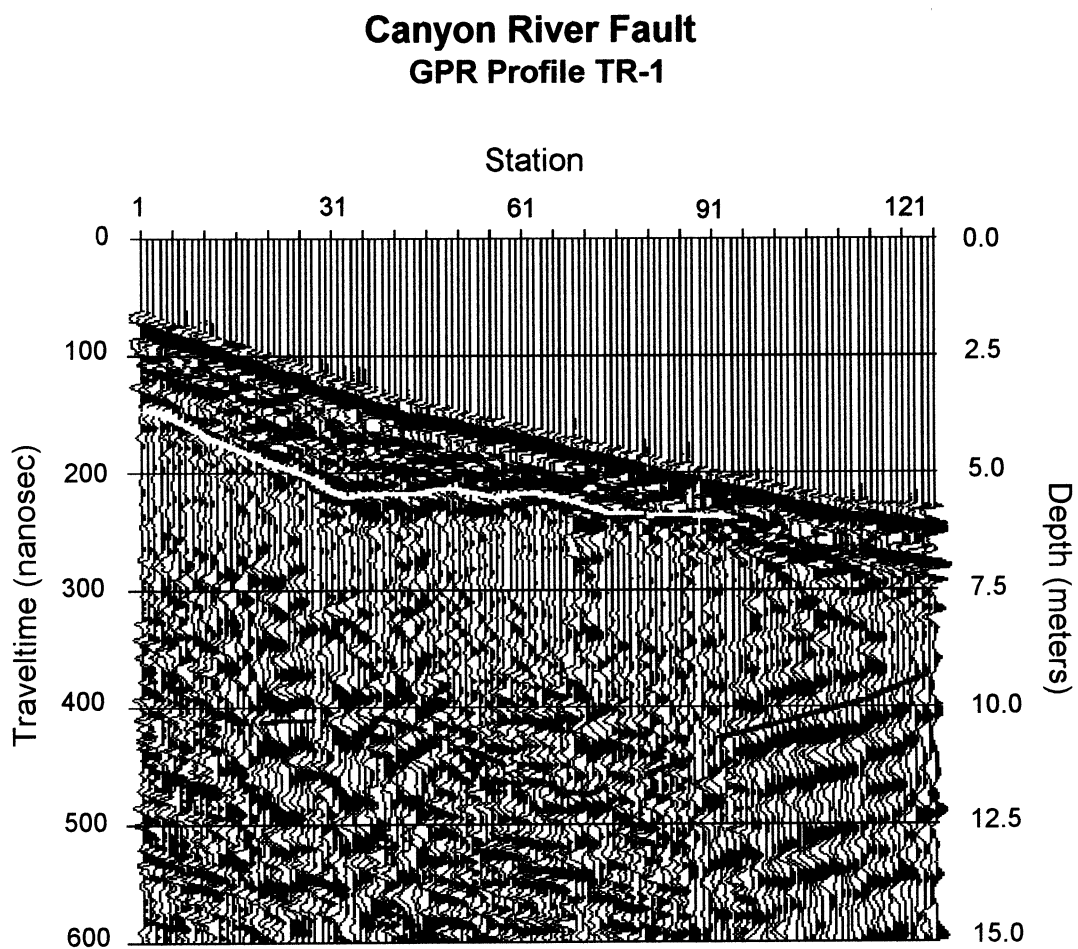
Figure A-1

Location of GPR profiles TR-1 and TR-2. Base of the Canyon River scarp is shown.



**Figure A-2**

Interpretation of GPR profile TR-2 across the Canyon River Fault. Orange reflector is interpreted as bedrock, and is offset by the near-vertical fault in red. Bedrock on the downthrown side of the fault is estimated to be at approximately 5 to 6 m (16.5 to 20 ft) depth.



**Figure A-3**

Interpretation of GPR profile TR-1 across the Canyon River Fault. Orange reflector is interpreted as bedrock on the down-thrown side of the fault. Depth to bedrock at the base of the scarp is estimated to be approximately 3 to 4 m (10 to 13.5 ft). Yellow reflector is interpreted as a fan resulting from debris flows originating on the steep slope bounding the north side of the sag pond.

**ACTIVE FAULT INVESTIGATIONS ON THE CANYON RIVER FAULT,  
SOUTHERN OLYMPIC RANGE, WASHINGTON**

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**Non-technical Summary**

We have investigated a fault in the southeastern Olympic Mountains of Washington state called the Canyon River fault (CRF). The CRF is part of a structure that is at least 30 miles long. If it is capable of generating earthquakes, they would likely be large enough (magnitude of 6.5-7) to put several dams and small cities at risk. Preliminary work suggests that the fault has been active within the last 2,000 years and so presents a seismic hazard in the southeastern Olympics.